PART FOUR

Air Environment

Chapter 18

THE ATMOSPHERE

The atmosphere is sometimes called "an ocean of air surrounding the Earth." You might also find it referred to as an "envelope of air," or as a "gaseous covering." Both are acceptable, but in this chapter the atmosphere will not be given a descriptive name. Instead, it will be examined for what it is: gaseous fluid that reacts to any force.

Objectives

Describe atmosphere and space as one medium termed aerospace.
Identify the atmospheric elements.
Recall the four ways of describing atmospheric regions.
Define the various atmospheric regions.
State the general characteristics of atmospheric pressure.
Define the atmospheric regions.
Describe the evaporation cycle.
State the difference between condensation and precipitation.
Identify the role of particulate matter in the water cycle.
Define water vapor, dew-point temperature, solar radiation, sublimation, humidity, relative humidity and condensation nuclei.
Classify the four principal ways in which heat is transferred.
Define insolation.
Describe the importance of heat balance.
Explain the Coriolis effect.
Identify the types of pressure patterns used to depict pressure gradients on weather maps.
Describe the effect of gravity, friction and centrifugal effect (force) on the wind.
Explain the land and sea breeze phenomena.
Describe how turbulence can form around mountains.
Describe the general characteristics of the jet stream.

What is the Atmosphere?

Before discussing the atmosphere, the two concepts "atmosphere" and "space" need to be clarified. Many people still believe the atmosphere and space are two separate regions. This is understandable knowing that an unprotected human being can live in the atmosphere, but not in space. We also know that the airplane can fly within the atmosphere, but cannot fly in space. For these reasons, it is natural for people to assume that space must be separate and different from the atmosphere.

The problem is in searching for the dividing line between space and the atmosphere. Even scientists disagree as to where the atmosphere ends and space begins. There are some people on Earth who live, work and play high in the mountains where most of us would have difficulty breathing. These people,

over generations, have adapted to living in the very thin atmosphere. Who is to say that people could not adapt to living at even higher altitudes if given enough time to do so? Airplanes can now fly much higher and in much thinner atmosphere than they once could. Thus, the dividing line between the atmosphere and space has, as far as people's activities are concerned, been moved higher and higher over a period of time.

No boundary line between atmosphere and space is found by looking at the composition of the atmosphere either. The only change is a gradual increase in the distance between the molecules and atoms that makeup the atmosphere. Considering these factors there is only one conclusion possible. The atmosphere and space are really one medium which is best described by the compound term aerospace (aero = atmosphere plus space).

The Earth's Atmosphere

For the purpose of this text, the word atmosphere will be used to describe the aerospace portion where humans do not require special life support systems and space will be used to define the area above the atmosphere where special equipment is needed.

Later, chapters will show in more detail how the Earth's atmosphere is divided and named. Once beyond this measurable atmosphere, it is generally accepted that all else is space, and space extends in all directions for an infinite distance. The realm of "true" space has also been given names; these names—whether they pertain to the atmosphere, to space or to aerospace—are necessary as points of reference for the communication of thoughts and facts.

Describing the Atmosphere

The atmosphere is a complex mixture of molecules and atoms. It is not easily or quickly described, but there are three major ways to study the makeup of the atmosphere: its *elements*, its *regions*, and its *pressure.*

Atmospheric Elements

The atmosphere is composed of 78 percent nitrogen and 21 percent oxygen. This leaves only one percent to be made up by other permanent and variable gases. The other permanent gases are argon, neon, helium, methane, hydrogen and xenon. The variable gases are water vapor, carbon dioxide, ozone, carbon monoxide, sulfur dioxide and nitrogen dioxide. Added to this pure mixture there are also dust particles, hydrocarbons and other matter given off by vehicles and industries, the pollens of plants, and so forth.

Atmospheric Regions

Certain levels of the atmosphere can be identified according to general characteristics, or atmospheric regions. The four usual ways of describing these regions (also called atmospheric shells or layers) are by temperature distribution, physicochemical (physical and chemical properties) processes distribution, molecular composition and dynamic-kinetic (force-motion) processes.

Temperature Distribution. One of the most common and easiest ways to understand and describe the atmosphere is by temperature. There are four distinct regions of the atmosphere where the temperature distribution is different enough to warrant a different name.

The Troposphere and Tropopause. The troposphere is that region in which most people live, work, play and fly. It extends from the Earth's surface to about 10 miles above the Earth at the Equator (55,000 feet). In the Polar Regions, the troposphere is only slightly more than 5 miles in height (28,000 feet). The reason for this is the change in the air temperature between the poles and the Equator. The prefix "tropo" means to turn or change (sphere = layer), and this is just what the troposphere does. The atmosphere within this region is constantly turning and changing as it produces what is known as weather.

In general, temperatures within the troposphere go down with increase in altitude at a fairly constant rate. There are many factors which affect this rate, but it is generally accepted to be 2° Celsius (C) or 3.5° Fahrenheit (F) decrease with each 1,000 feet gained in altitude. This is known as the standard lapse rate (temperature).

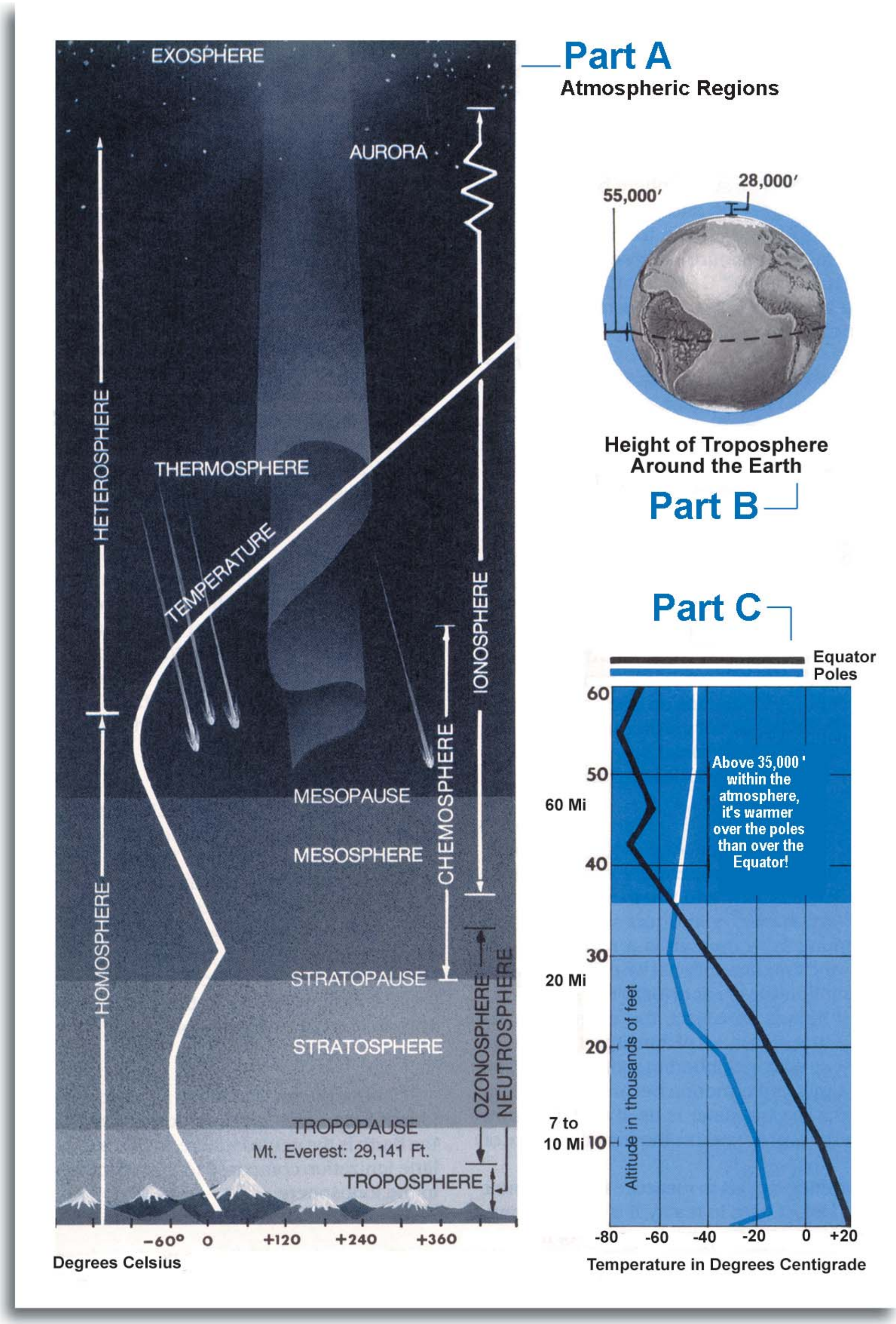
The tropopause is at the top of the troposphere (where the atmosphere becomes stable). The tropopause is the dividing line between the troposphere and the next higher layer (the stratosphere). The tropopause is not a distinct dividing line. It undulates like the gentle swells of a calm sea as large areas of the atmosphere in the troposphere rise when heated and descend when cooled.

Also, there are "steps" within the tropopause. These steps are found where the jet streams occur. Jet streams are "tubes" of very high-speed air which encircle the Northern and Southern Hemispheres. These jet streams are the upper-level dividing lines between the polar troposphere and the equatorial (or tropical) troposphere.

The Stratosphere and Stratopause. The next region of the atmosphere is called the stratosphere. In this region, temperature goes up with increase in altitude. The stratosphere begins at 10 or so miles above the Earth and extends upward to about 30 miles. From the base to the top of the stratosphere, the temperature goes up from about -60° C (-76° F) to about -40° C (-40° F). At 30 miles up, the warming trend stops and there is another dividing line called the stratopause.

The Mesosphere and Mesopause. The next region is the mesosphere. From the stabilized -40° C stratopause, the mesosphere first shows a marked increase in temperature to 10° C (50° F), then a decrease until at about 50 miles altitude where the temperature has dropped to as low as -90° C (-130°F). This point is called the mesopause.

Thermosphere. From 50 miles outward to about 300 miles, there is the region called the thermosphere. Here, the temperature increases again. How much it goes up depends on solar activity, but it


Part A
Atmospheric Regions
EXOSPHERE
AURORA
HETEROSPHERE
THERMOSPHERE
TEMPERATURE
IONOSPHERE
CHEMOSPHERE
MESOPAUSE
MESOSPHERE
HOMOSPHERE
STRATOPAUSE
STRATOSPHERE
OZONOSPHERE
NEUTROSPHERE
TROPOPAUSE
Mt. Everest: 29,141 Ft.
TROPOSPHERE
-60° 0 +120 +240 +360
Degrees Celsius
55,000′
28,000′
Height of Troposphere Around the Earth
Part B
Part C
Equator
Poles
Above 35,000 ' within the atmosphere, it's warmer over the poles than over the Equator!
60 Mi
20 Mi
7 to 10 Mi
60 50 40 30 20 10
Altitude in thousands of feet
-80 -60 -40 -20 0 +20
Temperature in Degrees Centigrade

is usually between 750° C (1,380° F) to 1,250° C (2,280° F). At this point, we are in space and temperature is a relative sort of thing. It depends on one's closeness to the Sun and whether or not the thermometer is in direct sunlight or is shaded from the Sun.

Physicochemical Processes Distribution. Atmospheric regions can also be described by the distribution of various physicochemical processes that happen in them. Included in this atmospheric classification are the ozonosphere, ionosphere, neutrosphere and chemosphere.

Ozonosphere. The ozonosphere is a special region, or global shell, that extends from about 10 to 30 miles altitude. In this region, the Sun's radiation reacts with the oxygen molecules and causes them to pickup a third atom creating ozone. The ozonosphere performs the very important function of shielding us from ultraviolet and infrared radiation that could be fatal.

Ionosphere. The ionosphere begins at an altitude of about 25 miles and extends outward to about 250 miles. Because of interactions between atmospheric particles and the Sun's radiation, there is a loss or gain in the electrons of the atoms and molecules, and thus the word "ion." The floor of the ionosphere reflects certain radio waves. This allows them to be received at stations far away from the broadcasting station.

Neutrosphere. The shell, or region, below the ionosphere that extends down to the surface of the Earth is the neutrosphere. In this region, there is little ionization compared to that which takes place in the ionosphere.

Chemosphere. The neutrosphere, ozonosphere and ionosphere extend upwards (vertically) without overlapping. The chemosphere is vaguely defined. It overlaps the ozonosphere and ionosphere and begins at about the stratopause, includes the mesosphere, and sometimes the lower part of the thermosphere. This is an important region because of a number of important photochemical (radiant energy and chemical) reactions occur within it.

This is the *ER*-2 airborne science aircraft. It is used to study Earth resources, celestial observations, atmospheric chemistry and dynamics, global warming and ozone depletion.

The *DC*-8 airborne laboratory conducts scientific studies in atmospheric chemistry, meteorology, oceanography and soil science.

Molecular Composition. Describing the atmosphere by its molecular makeup results in two main regions: the homosphere and heterosphere.

Homosphere. The homosphere extends from the Earth's surface up to an altitude of about 60 miles. The prefix "homo" means same; thus, the homosphere is that region in which the gaseous composition and mixing are relatively constant i.e., 78 percent nitrogen and 21 percent oxygen.

Heterosphere. The heterosphere (hetero is a prefix meaning different) begins around the 55- to 60-mile altitude. In the heterosphere the molecules and atoms of the gases are spaced much farther apart. At this altitude, gravity influences them according to mass and they take on a vertical arrangement. The heaviest, molecular nitrogen and oxygen are found in the lower part of the heterosphere. The lighter atomic oxygen, helium and hydrogen are in the upper part.

Dynamic and Kinetic Processes. The exosphere is the top of the atmosphere above the heterosphere. The dynamic and kinetic processes that occur within the region determine the exosphere. In this region, the particles of the atmosphere move in free orbits subject only to Earth's gravity. The bottom of the exosphere is estimated between 310 to 621 miles above the Earth's surface. The upper boundary of the exosphere extends into space without end.

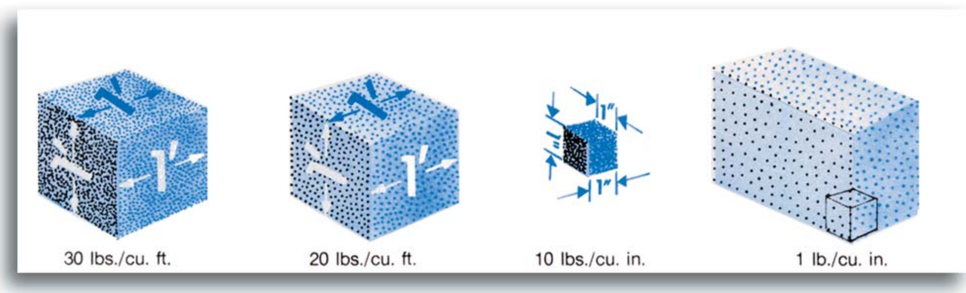
The exosphere begins in that region where the atmosphere's molecules and atoms are so far apart they would have to travel as far as 100 miles before running into another molecule or atom. Within this region an atmospheric particle with enough velocity can escape from Earth's gravitational influence. This is why the lower part of the exosphere is also known as the "region of escape."

There are several other regional classifications of the atmosphere that describe a particular condition or process that occurs. The thermal structure or temperature distribution is the most important. Within this structure, the troposphere will receive the most emphasis as it is where most of us spend our lives and it is where "weather" takes place. For a summary of the different classifications of the atmosphere, refer again to the chart on page 383.

Atmospheric Pressure

Earth's gravitational force is what keeps atmospheric molecules from sailing off into space. This force becomes stronger the closer something is to the center of gravity. Earth's center of gravity is considered to be near its core; therefore, gravitational influence is greatest at or below sea level on Earth.

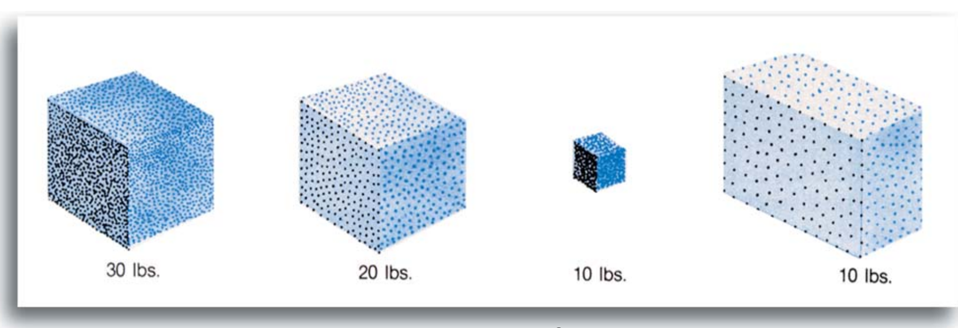
Density indicates how tightly the particles of matter are packed together. This is also known as "mass per unit volume. The density of air molecules decreases with increases in altitude. This happens for several reasons. Some molecules possess less mass than others. In addition, the molecules closer to the Earth are under more gravitational influence than molecules higher up. The most significant fact is the weights of all air molecules press down upon all the other molecules below them. This is called pressure.



Density: Mass Per Unit Volume

Pressure is exerted in all directions within a given volume of air. At sea level, the pressure averages about 14.7 pounds per square inch. The reason 14.7 pounds is an average is that the pressure at any one point fluctuates as cells of higher or lower pressure are formed and move across Earth's surface (this aspect of the atmosphere appears in a later section).

Air pressure decreases with gains in altitude because of the lessening effect of gravity and the greater distance between the numbers of molecules present. For example, the pressure at 18,000 feet (3.4 miles) is about one-half that at sea level. Going higher, to 35,000 feet (6.6 miles), we find the pressure less than one-fourth that of pressure at sea level. This rapid pressure decline continues the farther outward from Earth's surface we travel, until there is no measurable pressure. This is why pilots of very high-flying aircraft and astronauts must wear pressure suits. If they did not wear these



Mass: Amount of Material

suits, the “normal” pressure within their bodies would cause cells to rupture much like the way a balloon does when it rises into the upper atmosphere.

Roles of Water and Particulate Matter

Water in the Atmosphere. The water content of the atmosphere is almost restricted to the troposphere. There are occasions when a particularly heavy thunderstorm will produce enough energy to thrust part of its top into the stratosphere. Water may also be injected into the stratosphere by the engines of high-flying aircraft. Still, water is usually only found in the troposphere.

In the troposphere, however, water goes through a complete process cycle. From vapor, water goes to condensation then to precipitation.

As it goes through this cycle, it takes on several forms. Water is seen in liquid forms as lakes, rain, dew and even as perspiration on our bodies. It can be in solid form as ice, hail or snow. It also appears as fog and clouds—the condensation stage of its cycle.

Under normal conditions, water is not seen when it is part of the atmosphere—when it is a water vapor. If there is a relatively large amount of water vapor in the air, we say that it is humid, and when there is little water vapor, we say that the air is dry. However, no matter how dry the air may seem, there is always some water vapor present.

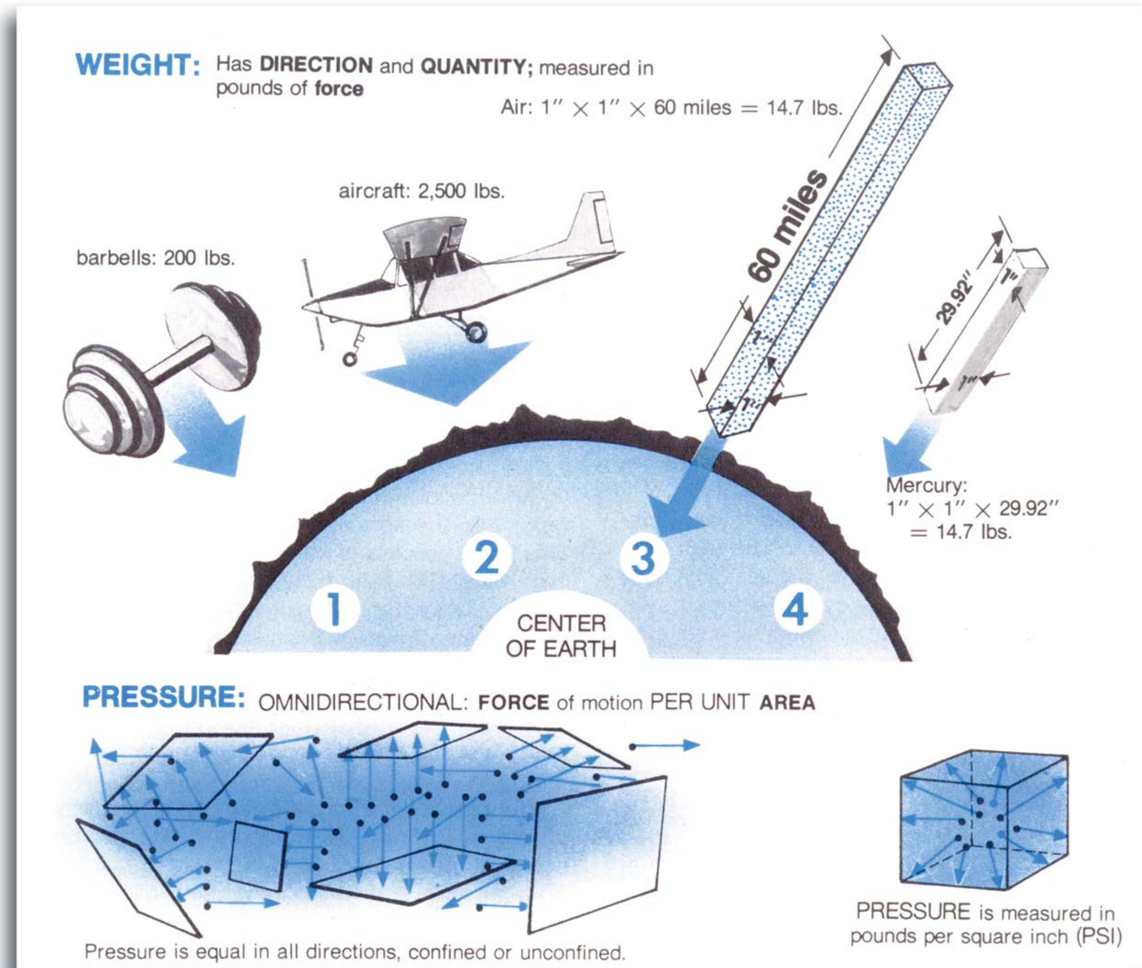
The air is said to be “saturated” when it cannot hold any more water vapor. The amount of water vapor that can exist in the air increases with rising temperatures. The higher the temperature of the air, the more water vapor the air per unit volume can hold before saturation is reached. The lower the air temperature, the less water vapor a given volume of air can hold before it becomes saturated. The term “dew-point” is best defined as the air temperature at which saturation occurs. Thus, the amount of water vapor that can actually be in the air will depend on the temperature at any given time.

In addition to temperature, pressure also affects how much water vapor a per unit volume of air can hold. Air is a gas and gases expand when the pressure on them decreases. As we gain altitude, pressure decreases and the air expands. This leaves more room for additional water vapor to enter a given volume of air and increases its saturation point.

Thus, the water in the atmosphere that falls to Earth as well as the amount will relate directly to the current temperature and pressure of the air. This concept is important in understanding the concept of relative humidity. The question at this point is how does water get into the air to begin with?

Evaporation. We know that temperature and pressure are the primary causes of water vapor in the air. What caused the vapor in the first place? The air is constantly gaining and losing water, and the water vapor gets into the air by a process called evaporation. Evaporation is the process by which liquid water molecules change to a gas or vapor state and enter the Earth’s atmosphere. The main factor in evaporation is temperature.

A simple example of evaporation due to temperature is seen with boiling water. The high temperature causes the water molecules to escape from the liquid surface and rise into the air. The molecules immediately condense as steam because they saturate the air into which they are escaping. Soon, the steam disappears as it evaporates into the surrounding air, because its dew-point temperature has been raised by the warm water vapor. If this vapor-laden air comes in contact with a surface cooler

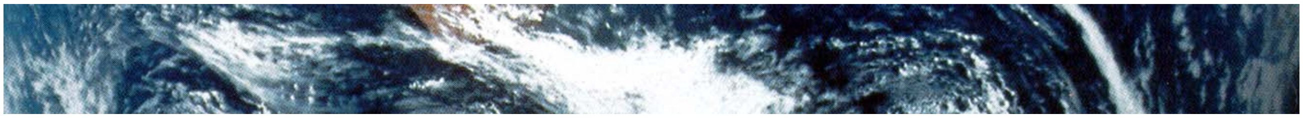


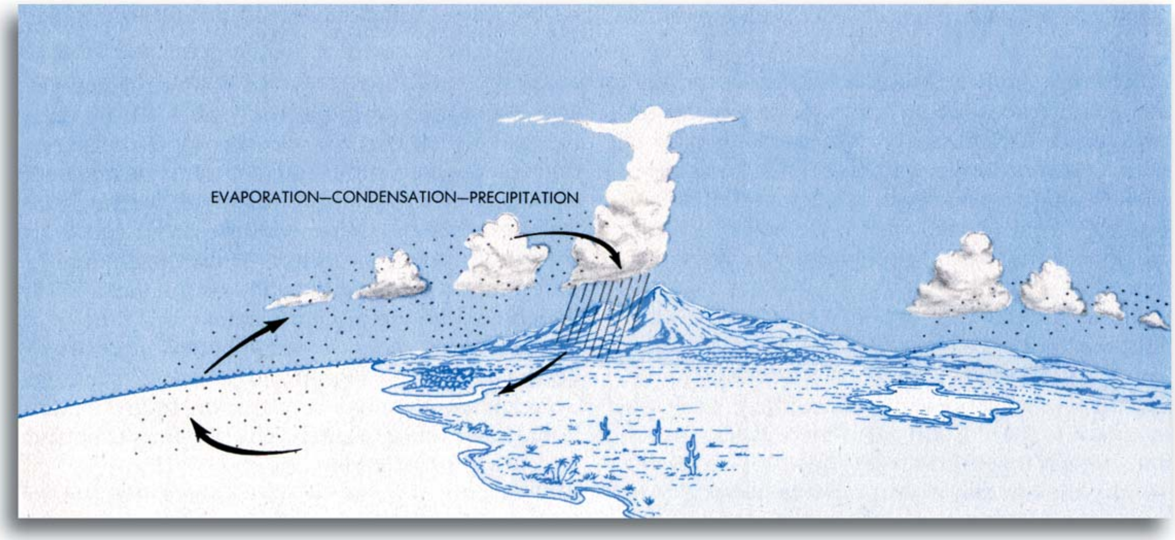
Weight is in one direction, while pressure is in *all* directions—both decrease when altitude increases.

than it, the air temperature drops below its dew point and the vapor condenses into a liquid and the wall or ceiling becomes wet.

Evaporation of water on a global scale takes place in a manner similar to the example above, but it is much subtler. Most of the water vapor in the atmosphere comes from the oceans and other large bodies of water. A process called solar radiation heats the water causing the evaporation. The warm moist air moves over cooler land and cools below its dew point causing the excess water vapor to fall back to the ground in some form of precipitation.

Another method of putting water vapor into the atmosphere is called sublimation. This happens when water molecules leave the frozen (solid) state and directly enter the atmosphere without first changing into a liquid. This process requires more heat energy than the evaporation process. You may have witnessed the sublimation process during the wintertime when snow on the ground disappears without having melted. Sublimation also describes the formation of frost. That is, water vapor doesn't condense first to a liquid before becoming frost; it goes directly from the vapor state to the frozen state.

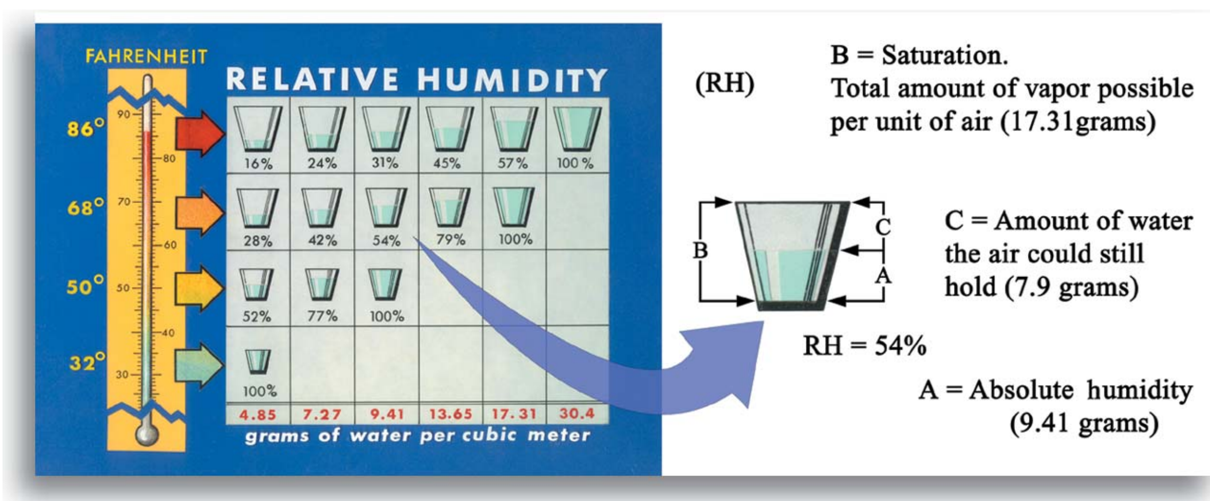




Evaporation Cycle

Humidity and Relative Humidity. Invisible vapor is the water form usually associated with humidity. While there are many ways of explaining humidity, the simplest approach begins by emphasizing that

1. temperature is the main cause of humidity and precipitation,
2. before precipitation can occur, there must be enough water vapor present,
3. the amount of water vapor the air is able to hold depends on the temperature of the air,
4. warm air can hold more water vapor than cold air, and
5. as air cools, its ability to hold water vapor decreases.



This chart shows relative humidity and temperature. When RH is 100% at a given temperature, the dew point is reached. It also shows that the ratio of A to B equals relative himidity and indicates how far away from saturation the unit of air is (C).

Humidity is the term that indicates the amount of water vapor in the air. Absolute humidity tells you the actual percentage of water vapor in the air at a given time. Relative humidity is the method used to tell you the amount of water vapor that can still enter an air mass before it becomes saturated. It is expressed as a percentage which is the ratio of the amount of water vapor in the air to the maximum amount that the same volume of air could contain at a given temperature and pressure.

When the air is holding the maximum amount of water vapor for the existing temperature (i.e., 68° F and pressure, the air is saturated (i.e., 17.31 grams) and the relative humidity is 100 percent. However, if the same unit of air were only holding a little more than half of the amount of water vapor it is capable of at that temperature, the relative humidity would be 54 percent (junction of 68° F and 9.41 grams). This would leave 46 percent more water vapor that the given air mass could hold at 68° F.

Looking at the figure on page 389 may make this relationship clearer. The ratio of A to B equals the relative humidity—a percentage indicator of how much more water (C) that the unit of air at 68° F could hold before reaching the saturation point (B), or 17.31 grams of water vapor. In this case, the unit of air could accept up to 7.9 grams more of vapor before it would be saturated. The relative humidity number is indicating how much more vapor the air is capable of holding at the time of measurement. This in turn gives a fair idea of when condensation and/or precipitation might occur—particularly important factors for pilots.

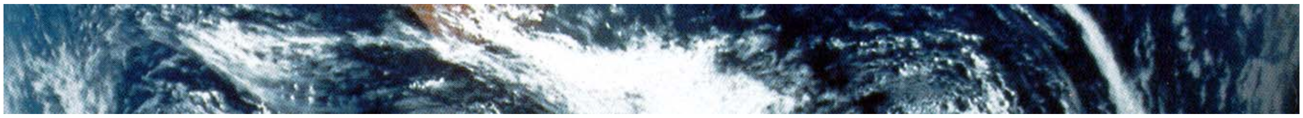
Condensation and Precipitation. Periodically, part of the water vapor in the air returns to a liquid or solid form and is seen as condensation or precipitation. Clouds, fog, dew and frost are forms of condensation. Rain, sleet, snow and hail are forms of precipitation. If visible water falls, it is precipitation; if it does not, it is condensation.

Condensation and precipitation occur due to lowered temperatures. Since cold air holds less moisture than warm air, simply lowering the temperature can increase the relative humidity. In doing so, the air holds less vapor and, if it is already saturated, the excess vapor condenses or turns into precipitation. If the temperature gets lower, and there is particulate matter in the air, the vapor can quickly change to a liquid state — a potential hazard to a pilot. If the air is cold enough, it can freeze and cause freezing rain — an even worse hazard for a pilot.

Dew Point Temperature. The dew point temperature is the key factor in condensation and precipitation. The dew point temperature is the temperature at or below which water vapor will condense. This does not say that there will be clouds, rain, snow, fog, etc., as a result of condensation. On the contrary, it indicates that some type of condensation will take place if the air temperature drops to a certain level. When compared to the actual air temperature, it also reveals how close the air is to saturation and how close the air is to forming condensation and precipitation.

Condensation and precipitation might be expected if the temperature dropped to 50° F (with no further vapor added to the air mass). This would be the dew point temperature. Relative humidity will have increased to 100 percent indicating that no more water vapor can be accepted into the air mass, without condensation and precipitation probably occurring.

The difference between the actual and the dew point temperature is called the "spread." Relative humidity increases as the temperature spread decreases and is 100 percent when the spread is zero. At the dew point temperature, moisture in the air will condense to form clouds at higher altitudes and fog



on the ground. Under the right conditions, precipitation could also occur. When the spread is within 4 degrees and the difference is getting smaller, fog should be expected.

Nothing about Earth's atmosphere and its weather is simple, because of the almost constant changes experienced at any single location. For example, a parcel of air could have its water vapor content changed quickly if another parcel of air came along and the two merged their individual characteristics. That is a warm and moist parcel that could mix with a cold and dry parcel.

If the mix were sudden, there would be some condensation because the temperature of the warm, moist air parcel would be lowered. At the same time, the cold, dry air parcel would be warmed. The net result would be a new parcel of air with a capacity for holding an amount of water vapor that would be somewhere between that of the warm air and the cold air before the mixing took place. In everyday weather, this sort of thing takes place all the time.

Particulate Matter

Dust and other very small particles called particulate matter play an important role in weather. If they were not present in the atmosphere, there would not be certain forms of condensation and precipitation.

These particles serve as a surface for condensation of water vapor and are called condensation nuclei. The molecules of water attach themselves to these nuclei if the temperature is right. Water molecules continue to accumulate until they can be seen in their familiar liquid or solid forms. For an idea of just how small the condensation nuclei might be, the diameter of a single condensation nucleus could be as small as 0.000000004 inch (four billionths of an inch).

Atmosphere in Motion

The atmosphere is in constant motion in all directions: up, down and sideways. This is why the weather is constantly changing. If a unit of air is thought of as being the center of a sphere, its movement can be in any of the directions possible from the center of the sphere outward. This unit of air can be very small or it can involve hundreds of cubic feet.

There are two primary causes of atmospheric motion: heat and the motion of Earth. Heat comes from the Sun, and is critical in keeping the planet inhabitable. Thus, it is essential to examine how this thermonuclear heating system works.

Heat and Temperature

The heat energy contained within the atmosphere is responsible for all the Earth's weather processes. In review, remember the atmosphere is composed of molecules that are in constant motion. Because of this motion, the molecules possess energy. Heat is the sum total energy of all moving molecules within a substance. If something has a great deal of heat, the total energy of motion of all the molecules in the substance is high. Temperature, on the other hand, is a measure that expresses an

average of the energy of molecular motion. Heat is a form of energy, and energy can be transformed and transferred.

Methods of Heat Transfer

There are four principal ways in which heat is transferred from one place to another. These are called conduction, convection, advection and radiation.

Conduction. When one molecule (energized to a higher level of molecular motion through the heating process), contacts another molecule, the second molecule absorbs some of this heat. This is why the air above a layer of hot concrete, for example, becomes warmer than other surrounding air. Heating by direct contact is called conduction.

Convection. Any heat transfer by vertical motion is called convection. An example is the rippling effect of air above a hot runway or highway in the summer. The air over these hot surfaces rises much more quickly than the air over surrounding surfaces. Thus, vertical currents are established in the atmosphere; some parcels of air are heated and rise, and other parcels of air are cooled and descend.

Advection. When the wind blows, it is simply movement by or within the local air mass. Since that air mass has a certain temperature, that temperature will be transferred horizontally over the surface of the Earth by blowing winds or moving air masses. This process of lateral heat transfer is called advection. Advection is an important factor in the global circulation of air.

Radiation. The heat energy of the Sun reaches Earth as radiation. This method transfers heat energy without changing the temperature of anything between the source of energy and the object heated. Heat energy escapes a generating source in the form of waves. These radiant waves (or rays) are themselves a form of energy and are part of the electromagnetic spectrum, which includes visible light. When radiant energy from one object reaches another object and is absorbed, the radiant energy is changed into some other form of energy, often heat.

You can experience the effect of radiation, and its consequent heating effect, with an ordinary electric light bulb. Place your hand within one foot or so of a lighted bulb and hold it there for at least 30 seconds. The radiant energy from the light bulb will warm your hand considerably. The same effect can be felt with a flashlight, but your hand will have to be much closer to the flashlight because it generates much less radiant energy than the light bulb. The radiant energy that comes from the light bulb or the flashlight and warms your hand is the same principle as sunlight warming the Earth.

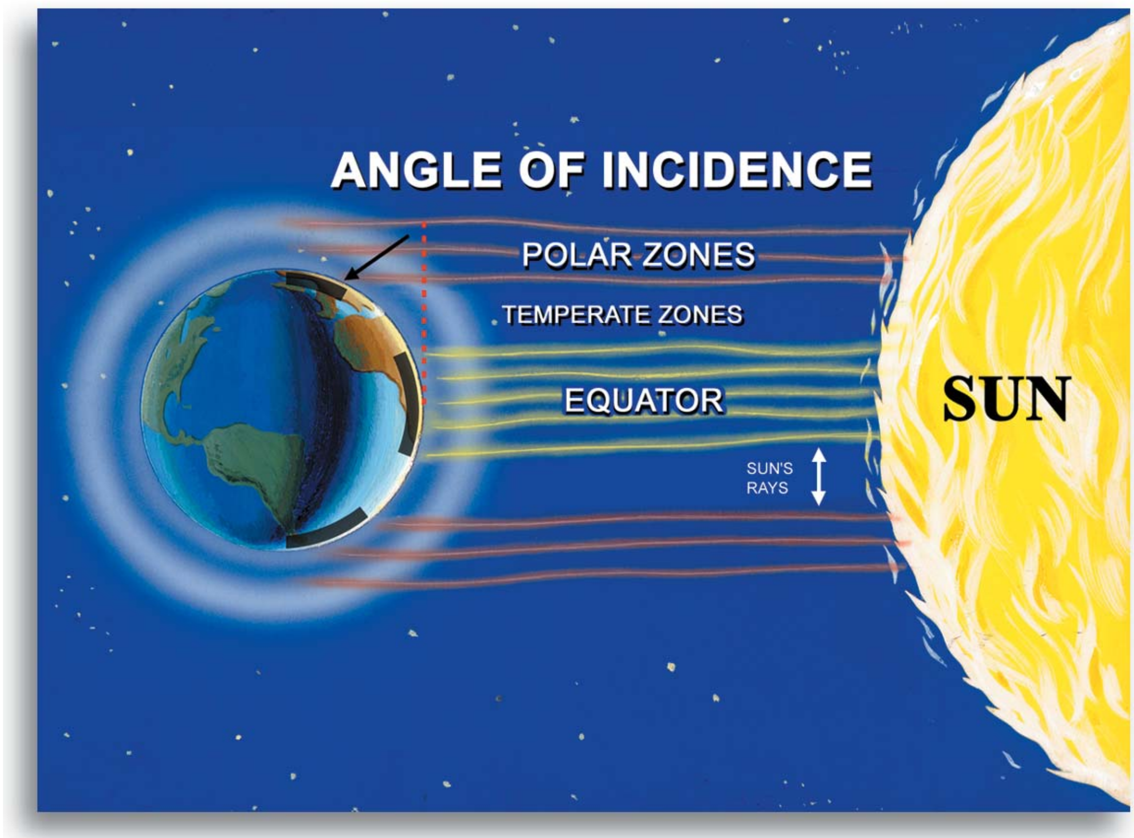
Although radiant energy is never destroyed, it may be changed in many ways. Radiant waves may be absorbed or reflected by the clouds, scattered or reflected by dust in the air, or absorbed by the Earth and converted into heat energy.

As stated before, the evaporation process requires a lot of heat (radiant energy). Although the radiant energy is absorbed by the water, there is no increase in the temperature of the water vapor that results; no heat is lost.

When the water vapor later condenses, heat is released and does affect the temperature of the surrounding air. This heat is known as the latent heat of condensation. This is a point to be remembered, since the heat released in this manner is a prime source of atmospheric energy. It is this latent heat energy which fuels such violent atmospheric disturbances as thunderstorms, tornadoes and hurricanes.

Insolation

The rate at which the Earth's surface is heated by solar radiation is called insolation. The amount of insolation received at any point on the Earth's surface depends on several factors: the angle the Sun's rays make with the horizon (called the angle of incidence), the distance of the Earth from the Sun and the amount of radiation absorbed by the atmosphere. On clear days more radiation reaches the Earth's surface than on cloudy days. Very dense cloud formations may reflect as much as three-fourths of the radiant energy from the sun.



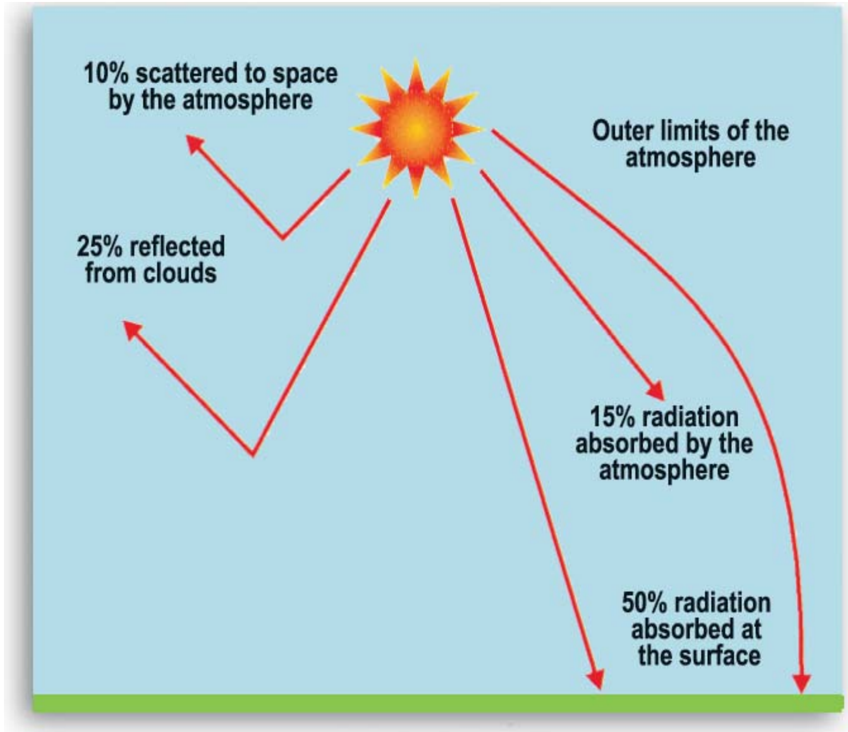
Insolation varies with latitude.

Insolation is greatest in the equatorial zone. The Sun's rays are nearly perpendicular to the Earth's surface. Therefore, more radiant waves per equal area (hence, more heat) reach the equatorial zone than reach the temperate zones, and more reach the temperate zones than reach the polar zones.

The Heat Balance

If there were no balance of heat between the Earth, its atmosphere and space, the Earth would become increasingly warmer. This does not happen because the insolation is in turn radiated back from the Earth into space or the atmosphere.

It is estimated that of all the solar radiation arriving at the top of the atmosphere, 30 percent is reflected into space by clouds and atmospheric dust, 20 percent is absorbed directly into the atmosphere, and 50 percent reaches the Earth. Of the 20 percent absorbed directly into the atmosphere, 4 percent eventually reaches the Earth as diffused sky radiation. Thus, about 55 percent of all the incident solar radiation reaches the Earth and heats it.



Solar Radiation

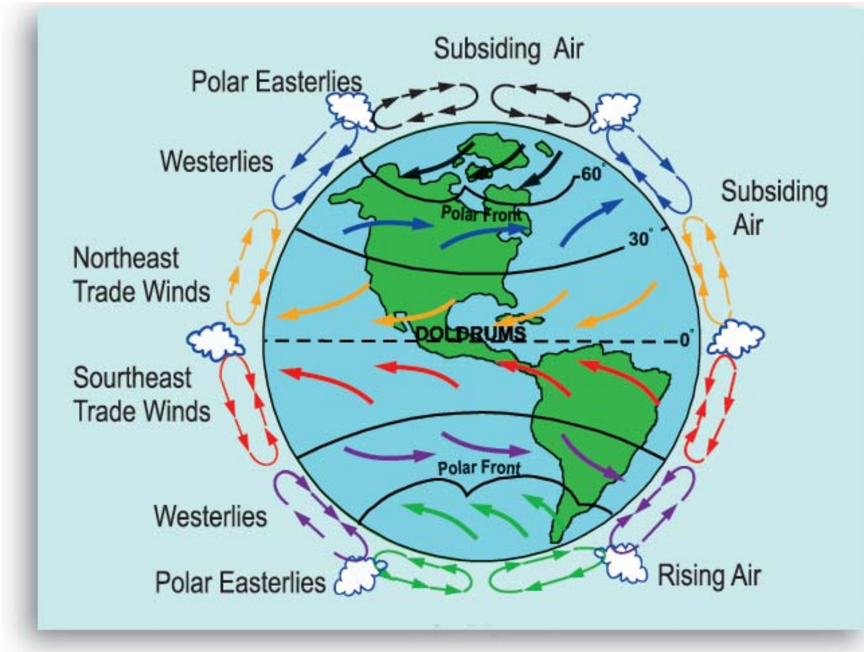
The heated Earth's surface, in turn, radiates infrared rays upward. Part of these rays (about 39 percent) are absorbed by the atmosphere are converted into heat. This process provides the principal source of heat for the troposphere. The rest of the infrared rays (about 8 percent) escape into space with no heating effect. The radiative processes that tend to maintain the Earth's heat balance are also chiefly responsible for worldwide weather.

Wind

Heated air rises. It rises because the heat applied to it has decreased its density to the point where it is lighter in weight than the surrounding air, and the surrounding, cooler air pushes the parcel of lighter air upward. This same effect can be seen in the flight of a hot-air balloon.

When this heated air rises, cooler, higher-pressure air flows sideways to fill the lower-pressure area created. This lateral movement is referred to as wind. Basically, the same type of exchange takes place on a global level, but in much larger proportions. All along the equatorial zone the air is heated more than at any other area. In the Polar Regions, where the angle of incidence is least, the least amount of heating takes place. The general trend is, therefore, for the cold air from the Polar Region to flow toward the Equatorial Zone. This occurs while the heated air of the equatorial zone is rising and drifting toward the poles.

The rotation of the Earth complicates this simple concept of wind. The rotation causes the alternating heating and cooling of the equatorial and other regions during day and night. Perhaps the most significant influence on the creation and flow of wind is the spinning planet and the resulting Coriolis Effect.



Global Winds

Coriolis Effect

The atmosphere is a part of the Earth held by the Earth's gravity. However, the atmosphere is not rigidly attached to the Earth. The atmosphere may move with relationship to the Earth, and the Earth may move with relationship to the atmosphere.

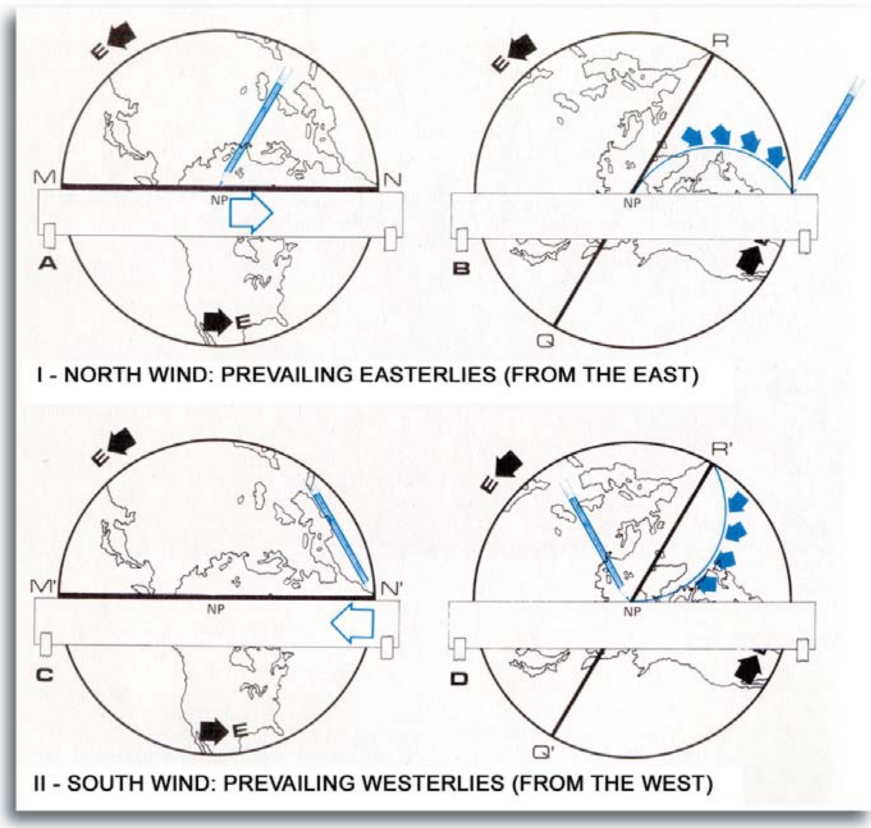
The Earth rotates on its axis in such a way that an observer in space over the North Pole would see the Earth turning in a counterclockwise direction. The rotation of the Earth influences any object moving over its surface. This influence is called the Coriolis Effect after the French physicist who first explained it in 1835.

The Coriolis Effect can be illustrated by imagining the Earth as the turntable on a record player with the center of the turntable representing the North Pole and the rim being the Equator.

1. Place paper on top of the turntable and cut it to the same circular dimension.
2. Start the turntable rotating in a counterclockwise direction.
3. Using a ruler and pencil, quickly draw a straight line from the center (North Pole) to the rim (Equator) of the rotating turntable.

To the person drawing the line, the pencil line traveled in a straight line. When the turntable is stopped, it can be seen. The line is not straight but is curved to the right or west. Similarly, a line drawn from the rim (Equator) to the center (North Pole) of the turntable, the line would curve to the left or east.

Anytime the atmosphere is in motion, the Coriolis Effect caused by the rotation of the Earth influences it. The heated air rises over the Equator and begins to travel toward the poles. However, the Coriolis effect acting on this mass of moving air will deflect it to the east in the Northern Hemisphere. By the



Example of the Coriolis Effect

time this air mass reaches 30° N latitude, it is no longer traveling north. It has been deflected and is moving straight east. As the mass of air cools, it becomes denser and sinks toward the earth, creating a high-pressure belt at this latitude.

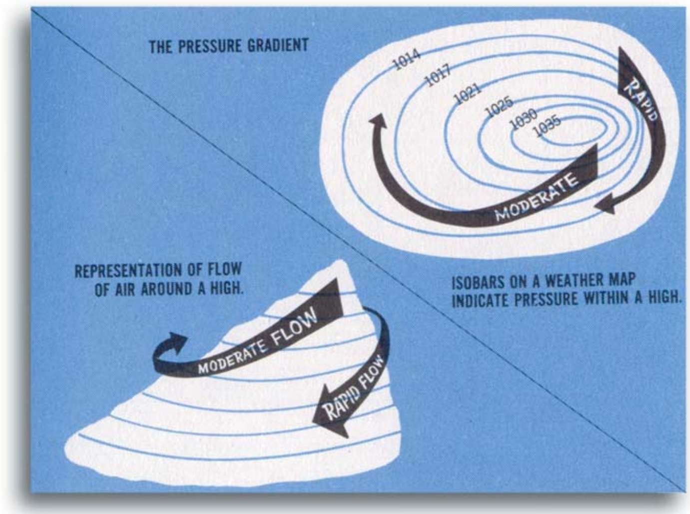
As the air pressure builds up within this belt, some of it is forced downward toward Earth's surface. A portion flows toward the Equator along the surface; another portion flows toward the pole along the surface. As these surface winds move toward the poles and the Equator, the Coriolis Effect again comes into play, deflecting the moving air masses.

The air flowing from 30° N latitude toward the Equator is deflected toward the west. This creates the trade winds that blow toward the southwest in the Northern Hemisphere. The air flowing from 30° latitude toward the North Pole is deflected toward the east. This creates the prevailing westerlies that blow toward the northeast between 30° N latitude and 60° N latitude. The same conditions occur in the Southern Hemisphere, but the directions of flow are reversed because the direction of rotation in the Southern Hemisphere is clockwise.

At the same time, some of the air aloft continues to flow toward the poles, cools, settles to the surface, and begins a return trip toward the Equator. The warmer surface air moving up from latitude 30° overruns this colder air and produces a high-pressure condition in the polar zones. When the polar high pressure becomes sufficient, massive cold-air surges break out of the polar zones. These surges of air move toward the Equator and cause the changing weather conditions of the middle latitudes.

The Pressure Gradient

Several factors cause the atmosphere to be a constantly changing landscape of invisible mountains and valleys. The major influences are the uneven distribution of oceans and continents, the seasonal temperature changes, the heat transferring qualities of different Earth surfaces and daily temperature changes. The high-pressure areas of the atmosphere are the mountains and the low-pressure areas are the valleys. The wind flows from these high-pressure mountains into the low-pressure valleys.



The Pressure Gradient

The slope of the high-pressure mountain is called the *pressure gradient*. On weather maps, its degree of steepness is shown by lines called *isobars*. Isobars are drawn through points of equal sea-level atmospheric (barometric) pressure. They identify five different types of pressure patterns—highs, lows, cols, troughs, and ridges. A *high* is a center of high pressure surrounded by lower pressure, and a *low* is a center of low pressure surrounded by higher pressure. A *col* is a "saddle-back" area between two highs and two lows. An elongated area of low pressure is called a *trough*. An elongated area of high pressure is called a *ridge*.

Other Factors Affecting the Wind

Other factors that affect the circulation of the air (wind) are gravity, friction and centrifugal effect (also known as centrifugal force). Gravity tends to pull the air downward and produce a graduated air-density distribution, with the greatest air density near the Earth's surface. Friction tends to slow air movement from the Earth's surface up to 6,000 feet or more.

Centrifugal force acts on air moving in a curved path, and decreases its speed within a low-pressure area and increases it within a high-pressure area. In the Northern Hemisphere, the air flows clockwise around the high-pressure area (an anticyclone) and counterclockwise around a low-pressure area (a cyclone). In the Southern Hemisphere the directions are reversed.

It should be noted that at an altitude where surface friction ceases to affect wind movement, the wind always blows parallel to the isobars. At this level (called the wind level), pressure gradient, centrifugal effect, and the Coriolis Effect are in balance. The wind at this level is called the gradient wind. Its speed is always inversely proportional to the distance between the isobars. This means that when the isobars on a weather map are far apart, the wind is weak; when they are close together, the wind is strong. Aviators always try to take advantage of favorable winds, and plan and navigate their flights accordingly.

Local and Surface Air Movements

The general circulation of the air is complicated by the irregular distribution of land and water areas. Different types of surfaces vary in the rate at which they absorb heat from the Sun and transfer heat to the atmosphere. Seasonal changes and daily variations in temperature also affect this rate of transfer.

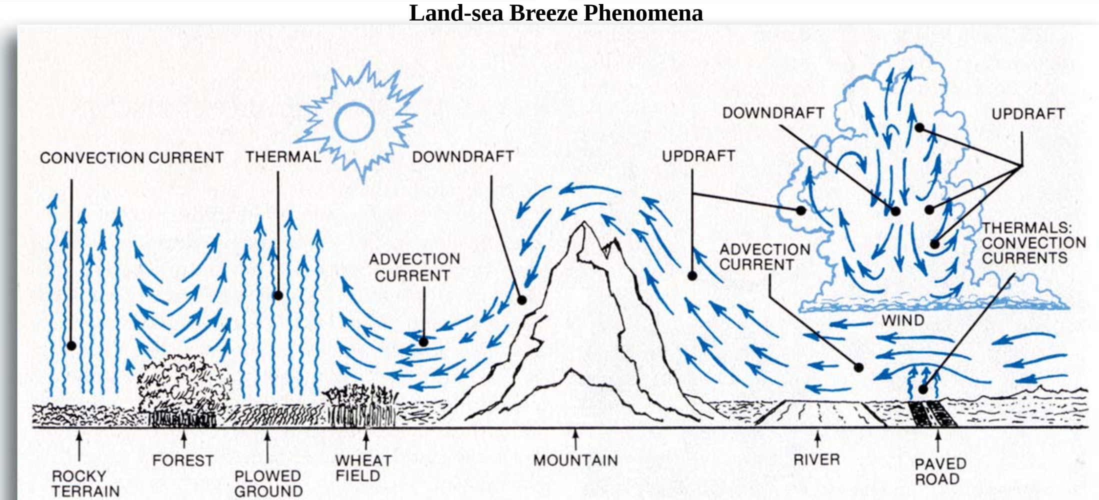
In some regions, local low-pressure areas form over hot land surfaces in summer, and over the warmer water surfaces in winter. Convection currents are formed along shorelines. These currents are

heated air rising upward which cause advection currents (wind) to flow from the water over the warmer land during the day. During the night, convection currents develop over the warmer-than-land water and cause the wind to blow from the land toward the water. This phenomenon is known as the land and sea breeze.

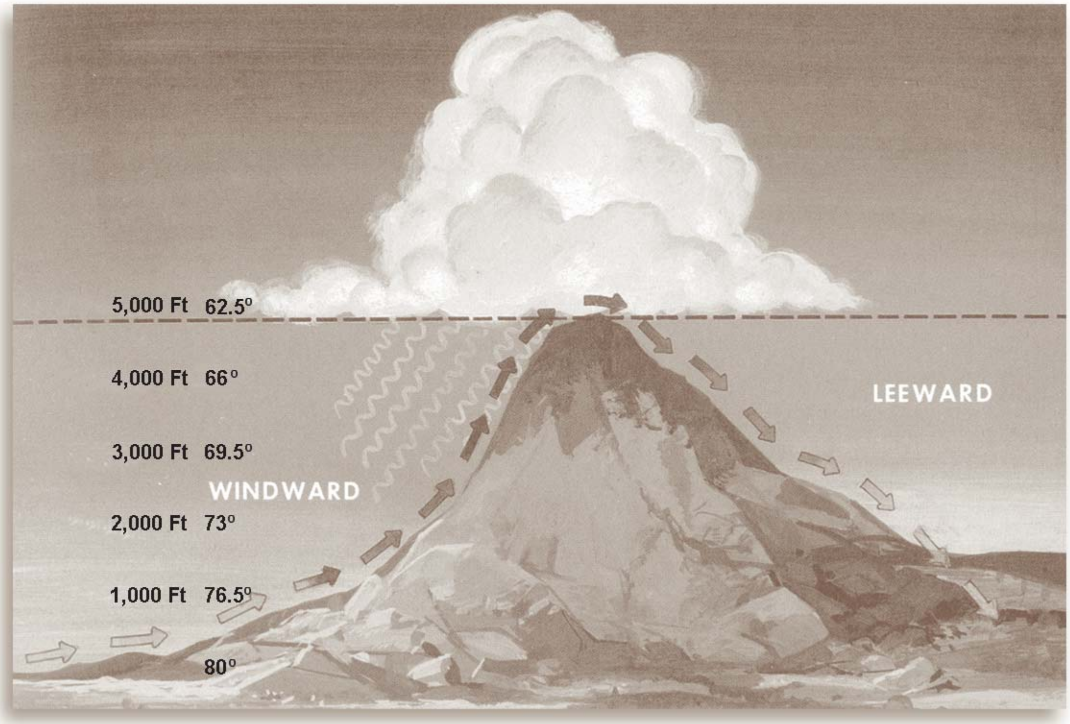
Local air circulation of limited scope is caused by variations in the Earth's surface. Some surfaces— such as sand, rocks, plowed areas and barren land—give off or reflect a great amount of heat. Other surfaces—such as meadows, planted fields and water—tend to retain heat. Rising air currents are encountered by aircraft flying over surfaces that give off considerable heat, while descending air currents are encountered over surfaces that tend to retain heat.

Moving air flowing around obstructions tends to break into eddies. On the leeward (opposite of the windward) side of mountains there are descending air currents. Such conditions cause turbulent air. The stronger the wind, the greater the descending air currents and turbulence. Aviators flying into the wind toward mountainous terrain should place enough distance between their aircraft and the mountaintops to avoid dangerous descending air currents.

Land-sea Breeze Phenomena



Thermals, advection currents, convection currents, wind, updrafts and downdrafts affect air movement.

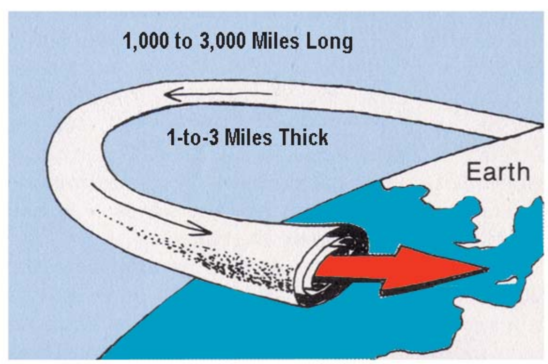


Descending Air Currents on Leeward Side of a Mountain

The Jet Stream

The jet stream, as mentioned earlier, is a comparatively narrow current of air which moves around the Northern (and Southern) Hemispheres of the Earth in wavelike patterns. It might be compared to a "river" of wind moving at high speed. The jet stream varies from about 100 to 400 miles wide and 1 to 3 miles thick. Its strongest winds are generally encountered above 30,000 feet. Jet-stream winds usually have a speed of 150-to-300 mph, but speeds up to 450 mph have been recorded. Its general motion is from west to east.

The jet stream shifts position frequently and actually migrates with the seasons. Sometimes two streams flow across the United States, one along the northern border and the other well toward the south. The cruising range of aircraft flying downwind within a jet stream is greatly increased. Pilots anticipating high-altitude or long-range flights attempt to discover the location of the jet stream and use it to their advantage.



The jet stream flows from west to east in wave-like patterns.

For several decades now, meteorologists have studied jet streams and how they affect the movements of air masses. While the relationship is still unknown, there is a common agreement that jet streams may act as a barrier between cold air in the north and warm air in the south. During their snakelike meandering, the streams appear to allow some cold air to flow southward and warm air to flow northward. These flows undoubtedly have some affect on the formation of cold and warm air masses.

Key Terms and Concepts

- atmosphere
- aerospace
- atmospheric elements
- four ways to classify atmospheric regions
- temperature distribution: troposphere, stratosphere, mesosphere, thermosphere
- physicochemical process distribution: ozonosphere, ionosphere, neutrosphere, chemosphere
- molecular composition: heterosphere and homosphere
- dynamic and kinetic processes: exosphere
- density, pressure and mass
- condensation
- humidity and relative humidity
- saturation
- dew-point
- evaporation
- solar radiation
- sublimation
- condensation and precipitation
- fog
- particulate matter
- condensation nuclei
- heat and temperature
- conduction
- convection
- advection
- radiation
- insolation
- Coriolis Effect
- pressure gradient
- isobars
- centrifugal force
- land-sea breeze phenomena
- jet stream

? Test Your Knowledge ?

SELECT THE CORRECT ANSWER

1. *The atmosphere and space are really one medium best described by the term* **(aeronautical / aerospace / aeroplane).**

FILL IN THE BLANKS

2. *Temperature is a measure of __________. A __________ is used to measure the amount of heat or the lack of it.*
3. *If visible water falls, it is __________; if it does not, it is __________.*
4. *Particulate matter can be in the form of dust, dirt, smoke, exhaust fumes or even salt particles. If the temperature is right, these particles can serve as __________ for __________.*
5. *The following terms are part of the __________ cycle:*
   dew-point temperature
   solar radiation
   sublimation
   saturate
6. *The difference between the actual and the dew-point temperature is called the __________.*
7. *The rate at which the __________ surface is heated by __________ radiation is called insulation.*
8. *The radiation processes that tend to maintain the Earth's __________ __________ are also chiefly responsible for worldwide weather.*
9. *Wind is generally referred to as a __________ movement of air.*
10. *The rotation of the Earth affecting anything moving over its surface is one way of defining the __________.*

MATCHING

11. *Heating by direct contact*	**a. Radiation**
12. *Process of lateral heat transfer*	**b. Advection**
13. *Heat transfers by vertical motion*	**c. Convection**
14. *Heat energy of the sun-reaching Earth*	**d. Conduction**

MULTIPLE CHOICE

15. *Centrifugal effect acts on air moving in a curved path and decreases its speed within a low-pressure area and*
    a. *decreases it within a high-pressure area.*
    b. *increases it within a high-pressure area.*
    c. *stops it within a high-pressure area.*
    d. *none of the above.*
16. *Friction tends to*
    a. *have no affect on air movement.*
    b. *increase air movement.*
    c. *slow air movement.*
    d. *all of the above.*
17. *Gravity tends to pull air downward with the greatest air density*
    a. *near the Earth's surface.*
    b. *next to the jet stream.*
    c. *at the tropopause.*
    d. *near the Sun.*
18. *Unequal heating by the Sun's rays of land and water areas causes*
    a. *the land and sea-breeze phenomena.*
    b. *the thermal downdraft.*
    c. *winds to stay aloft.*
    d. *none of the above.*
19. *Different types of Earth's surfaces vary in the rate at which they*
    a. *reflect the Sun's heat and transfer the Sun's heat to the atmosphere.*
    b. *absorb the Sun's heat and transfer the Sun's heat to the atmosphere.*
    c. *absorb the Sun's heat and transform heat to the atmosphere.*
    d. *avoid the Sun's heat and reflect heat to the atmosphere.*
20. *Jet streams shift positions frequently and*
    a. *have some effect on the formation of cold and warm air masses.*
    b. *can be compared to a river of air.*
    c. *actually migrate with the seasons.*
    d. *all of the above.*

TRUE OR FALSE

21. *Density is the comparison of how heavy something is to the space it fills.*
22. *Liquid water will evaporate only if there is space in the air for the water vapor molecules to occupy.*
23. *A high is a center of high pressure surrounded by higher pressure.*
24. *An elongated area of high pressure is called a ridge.*

25. *A low is a center of low pressure surrounded by even lower pressure.*
26. *An elongated area of low pressure is called a trough.*
27. *A col is a "saddleback" area between a high and a low.*

SHORT ANSWER

28. *Explain the difference between humidity and relative humidity.*
29. *Cite examples of how heat energy can be transformed and transferred.*
30. *Review the term standard lapse rate and solve the following problem: You are at the ocean beach on a hot summer day and the thermometer registers 92° F. What would be the temperature reading for the pilot directly above you flying at 8,000 feet?*
31. *The following examples involve atmospheric pressure. Give a brief explanation of each.*
    a. *The doors on a new car will not close unless a window is partially open.*
    b. *Your ears "pop" if you go up or down a mountain.*
    c. *You usually make two holes in the top of a metal can in order to remove the liquid.*